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Inventor(s)	Hammer; August D.

GNSS supplemented slope control system and method for a work vehicle

Abstract

A work vehicle including a chassis, a ground-engaging implement, an input device, a global positioning system, an implement sensor, and a controller. The implement movably connected to the chassis via a linkage assembly configured to allow the implement to be raised, lowered, and moved in a roll direction. The input device providing a bench surface, a desired cross slope, a desired mainfall slope, and a desired depth. The global positioning system configured to provide a chassis heading signal, a chassis inclination signal indicative of a main fall angle, and a chassis roll signal indicative of a cross slope angle. The sensor configured to provide a blade inclination signal and a blade roll signal. The controller configured to receive the signals, determine a distance error, and send a command to move the implement toward the desired mainfall slope and cross slope based on the distance error and towards the desired depth.

Inventors: **Hammer; August D. (Dubuque, IA)**

Applicant: **Deere & Company** (Moline, IL)

Family ID: **1000008748964**

Assignee: **DEERE & COMPANY (Moline, IL)**

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Primary Examiner: Redhead, Jr.; Ashley L

Background/Summary

FIELD OF THE DISCLOSURE

(1) The present disclosure relates to a work vehicle. An embodiment of the present disclosure relates to a system and method for supplementing the grade control of the work vehicle with a global navigation satellite system (“GNSS”).

BACKGROUND OF THE DISCLOSURE

(2) Work vehicles with ground-engaging implements may be used to shape and smooth ground surfaces. Such work vehicles may be supported by wheels or tracks which may encounter high and low spots on the ground as the work vehicles move, which cause the work vehicle to pitch forwards (downwards) or backwards (upwards). This pitching may be transmitted to the ground-engaging implement, causing it to move upwards and downwards relative to the ground, which may move

the implement off a designated or desired grade or plane. This effect may be amplified for those work vehicles with a ground engaging implements in front of the work vehicles' tires or tracks, as the work vehicle may pitch forwards or backwards as it encounters the vertical variations created by the ground-engaging implement due to earlier work vehicle pitching. If this effect goes uncorrected by an operator, it may create a “washboard” type surface on the ground or otherwise inhibit the creation of a smooth plane or grade on the ground.

SUMMARY OF THE DISCLOSURE

(3) According to an aspect of the present disclosure, a work vehicle may include a chassis and a ground-engaging blade movably connected to the chassis via a linkage assembly configured to allow the blade to be raised and lowered relative to the chassis and moved in a roll direction relative to the chassis. An input device may be included for providing a bench surface, a desired cross slope relative to the bench surface, a desired mainfall slope relative to the bench surface, and a desired depth relative to the bench surface. A global positioning system is communicatively coupled to the work vehicle. The global positioning system is configured for generating a chassis heading signal indicative of a location **150** of the work vehicle, a chassis inclination signal indicative of a main fall angle of the chassis relative to the bench surface, and a chassis roll signal indicative of a cross slope angle of the chassis relative to the bench surface. An implement sensor is configured to provide an implement inclination signal indicative of an angle of the implement relative to one of the chassis and the direction of gravity and an implement roll signal indicative of an angle of the implement in the roll direction relative to one of the chassis and the direction of gravity. A controller is configured to receive the bench surface, the desired cross slope, the desired mainfall slope, and the desired depth. The controller is further configured to receive the chassis heading signal, the chassis inclination signal, and the chassis roll signal. The controller is configured to receive the implement inclination signal and the implement roll signal. The controller is further yet configured to determine an inclination distance error based on the chassis inclination signal and the implement inclination signal, the inclination distance error indicative of a distance between the implement and the desired mainfall slope. The controller is configured to determine a roll distance error based on the chassis roll signal and the implement roll signal, the roll distance error indicative of a distance between the implement and the desired cross slope, and send a command to move the implement toward the desired mainfall slope and the desired cross slope, based on the inclination distance error and the roll distance error, and towards the desired depth.

(4) According to another aspect of the present disclosure, a method of controlling a ground-engaging blade of a work vehicle is disclosed. The method includes receiving a bench surface, a desired cross slope relative to the bench surface, a desired mainfall slope relative to the bench surface, and a desired depth relative to the bench surface. The method further includes receiving a chassis inclination signal indicative of a main fall angle of a chassis of the work vehicle relative to the bench surface. The method further yet includes receiving an implement inclination signal indicative of an angle of the implement relative to one of the chassis and the direction of gravity. The method further includes receiving a chassis roll signal indicative of a cross slope angle of the chassis relative to the bench surface. The method further yet includes receiving an implement roll signal indicative of an angle of the implement in the roll direction relative to one of the chassis and the direction of gravity. The method further includes receiving a chassis heading signal indicative of a location **150** of the work vehicle. The method further yet includes determining an inclination distance error based on the chassis inclination signal and the implement inclination signal, the inclination distance error indicative of a distance between the implement and the desired mainfall slope. The method further includes determining a roll distance error based on the chassis roll signal and the implement roll signal, the roll distance error indicative of a distance between the implement and the desired cross slope. The method further yet includes controlling the work vehicle to move the implement toward the desired mainfall slope and the desired cross slope, based on the inclination distance error and the roll distance error, and towards the desired depth.

(5) According to yet another aspect of the present disclosure, a crawler is disclosed. The crawler may include a chassis, a ground-engaging blade movably connected to the chassis by a linkage assembly configured to allow the blade to be raised and lowered relative to the chassis and moved in a roll direction relative to the chassis, a hydraulic cylinder, an electrohydraulic valve assembly configured to move the blade by directing hydraulic fluid to the hydraulic cylinder, an input device for providing a bench surface, a desired cross slope relative to the bench surface, a desired mainfall slope relative to the bench surface, and a desired depth relative to the bench surface. A global positioning system is provided that is communicatively coupled to the crawler. The global positioning system is configured for generating a chassis heading signal indicative of a location **150** of the crawler, a chassis inclination signal indicative of a main fall angle of the chassis relative to the bench surface, and a chassis roll signal indicative of a cross slope angle of the chassis relative to the bench surface. An implement sensor is coupled to the implement and configured to provide an implement inclination signal indicative of an angle of the implement relative to one of the chassis and the direction of gravity and an implement roll signal indicative of an angle of the implement in the roll direction relative to one of the chassis and the direction of gravity. A controller is configured to receive the bench surface, the desired cross slope, the desired mainfall slope, and the desired depth, receive the chassis heading signal, the chassis inclination signal, and the chassis roll signal, receive the implement inclination signal and the implement roll signal, determine an inclination distance error based on the chassis inclination signal and the implement inclination signal, the inclination distance error indicative of a distance between the implement and the desired mainfall slope, determine a roll distance error based on the chassis roll signal and the implement roll signal, the roll distance error indicative of a distance between the implement and the desired cross slope, and send a command to the electrohydraulic valve assembly to move the implement toward the desired mainfall slope and the desired cross slope, based on the inclination distance error and the roll distance error, and towards the desired depth.
(6) The above and other features will become apparent from the following description and accompanying drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) The detailed description of the drawings refers to the accompanying figures in which:
(2) FIG. **1** is a perspective view of a work vehicle, for example a crawler.
(3) FIG. **2** is a schematic of a portion of the work vehicle.
(4) FIG. **3** is an illustration of a ground profile created by the crawler as it drives over ground features.
(5) FIG. **4** is a schematic of a portion of a hydraulic system of the work vehicle.
(6) FIG. **5** is a left side view of the crawler driving over a ground feature.
(7) FIG. **6** is a flowchart of a method of actuating the blade of the crawler to create a target grade.
(8) FIG. **7** is a left side view of a work vehicle, for example a motor grader.
(9) Like reference numerals are used to indicate like elements throughout the several figures.
DETAILED DESCRIPTION OF THE DRAWINGS
(10) FIG. **1** is a perspective view of work vehicle **100**. Work vehicle **100** is illustrated as a crawler dozer, which may also be referred to as a crawler **101**, but may be any work vehicle with a ground-engaging blade or work implement such as a compact track loader, motor grader **600** (FIG. **7**), scraper, skid steer, and tractor, to name a few examples. Work vehicle **100** may be operated to engage the ground and cut and move material to achieve simple or complex features on the ground. As used herein, directions with regard to work vehicle **100** may be referred to from the perspective of an operator seated within an operator station **136**: the left of work vehicle **100** is to the left of

such an operator, the right of work vehicle **100** is to the right of such an operator, the front or fore of work vehicle **100** is the direction such an operator faces, the rear or aft of work vehicle **100** is behind such an operator, the top of work vehicle **100** is above such an operator, and the bottom of work vehicle **100** is below such an operator. While operating, work vehicle **100** may experience movement in three directions and rotation in three directions. Direction for work vehicle **100** may also be referred to with regard to longitude **102** or the longitudinal direction, latitude **106** or the lateral direction, and vertical **110** or the vertical direction. Rotation for work vehicle **100** may be referred to as roll **104** or the roll direction, pitch **108** or the pitch direction, and yaw **112** or the yaw direction or heading.

(11) Work vehicle **100** is supported on the ground by undercarriage **114**. Undercarriage **114** includes left track **116** and right track **118**, which engage the ground and provide tractive force for work vehicle **100**. Left track **116** and right track **118** may be comprised of shoes with grousers that sink into the ground to increase traction, and interconnecting components that allow the tracks to rotate about front idlers **120**, track rollers **122**, rear sprockets **124** and top idlers **126**. Such interconnecting components may include links, pins, bushings, and guides, to name a few components. Front idlers **120**, track rollers **122**, and rear sprockets **124**, on both the left and right sides of work vehicle **100**, provide support for work vehicle **100** on the ground. Front idlers **120**, track rollers **122**, rear sprockets **124**, and top idlers **126** are all pivotally connected to the remainder of work vehicle **100** and rotationally coupled to their respective tracks so as to rotate with those tracks. Track frame **128** provides structural support or strength to these components and the remainder of undercarriage **114**.

(12) Front idlers **120** are positioned at the longitudinal front of left track **116** and right track **118** and provide a rotating surface for the tracks to rotate about and a support point to transfer force between work vehicle **100** and the ground. Left track **116** and right track **118** rotate about front idlers **120** as they transition between their vertically lower and vertically upper portions parallel to the ground, so approximately half of the outer diameter of each of front idlers **120** is engaged with left track **116** or right track **118**. This engagement may be through a sprocket and pin arrangement, where pins included in left track **116** and right track **118** are engaged by recesses in front idler **120** so as to transfer force. This engagement also results in the vertical height of left track **116** and right track **118** being only slightly larger than the outer diameter of each of front idlers **120** at the longitudinal front of left track **116** and right track **118**. Frontmost engaging point **130** of left track **116** and right track **118** can be approximated as the point on each track vertically below the center of front idlers **120**, which is the frontmost point of left track **116** and right track **118** which engages the ground. When work vehicle **100** encounters a ground feature when traveling in a forward direction, left track **116** and right track **118** may first encounter it at frontmost engaging point **130**. If the ground feature is at a higher elevation than the surrounding ground surface (i.e., an upward ground feature), work vehicle **100** may begin pitching backward (which may also be referred to as pitching upward) when frontmost engaging point **130** reaches the ground feature. If the ground feature is at a lower elevation than the surrounding ground surface (i.e., a downward ground feature), work vehicle **100** may continue forward without pitching until the center of gravity of work vehicle **100** is vertically above the edge of the downward ground feature. At that point, work vehicle **100** may pitch forward (which may also be referred to as pitching downward) until frontmost engaging point **130** contacts the ground. In this embodiment, front idlers **120** are not powered and thus are freely driven by left track **116** and right track **118**. In alternative embodiments, front idlers **120** may be powered, such as by an electric or hydraulic motor, or may have an included braking mechanism configured to resist rotation and thereby slow left track **116** and right track **118**.

(13) Track rollers **122** are longitudinally positioned between front idler **120** and rear sprocket **124** along the bottom left and bottom right sides of work vehicle **100**. Each of track rollers **122** may be rotationally coupled to left track **116** or right track **118** through engagement between an upper

surface of the tracks and a lower surface of track rollers **122**. This configuration may allow track rollers **122** to provide support to work vehicle **100**, and in particular may allow for the transfer of forces in the vertical direction between work vehicle **100** and the ground. This configuration also resists the upward deflection of left track **116** and right track **118** as they traverse an upward ground feature whose longitudinal length is less than the distance between front idler **120** and rear sprocket **124**.

(14) Rear sprockets **124** may be positioned at the longitudinal rear of left track **116** and right track **118** and, similar to front idlers **120**, provide a rotating surface for the tracks to rotate about and a support point to transfer force between work vehicle **100** and the ground. Left track **116** and right track **118** rotate about rear sprockets **124** as they transition between their vertically lower and vertically upper portions parallel to the ground, so approximately half of the outer diameter of each of rear sprockets **124** is engaged with left track **116** or right track **118**. This engagement may be through a sprocket and pin arrangement, where pins included in left track **116** and right track **118** are engaged by recesses in rear sprockets **124** so as to transfer force. This engagement also results in the vertical height of left track **116** and right track **118** being only slightly larger than the outer diameter of each of rear sprockets **124** at the longitudinal back or rear of left track **116** and right track **118**. Rearmost engaging point **132** of left track **116** and right track **118** can be approximated as the point on each track vertically below the center of rear sprockets **124**, which is the rearmost point of left track **116** and right track **118** which engages the ground. When work vehicle **100** encounters a ground feature when traveling in a reverse or backward direction, left track **116** and right track **118** may first encounter it at rearmost engaging point **132**. If the ground feature is at a higher elevation than the surrounding ground surface, work vehicle **100** may begin pitching forward when rearmost engaging point **132** reaches the ground feature. If the ground feature is at a lower elevation than the surrounding ground surface, work vehicle **100** may continue backward without pitching until the center of gravity of work vehicle **100** is vertically above the edge of the downward ground feature. At that point, work vehicle **100** may pitch backward until rearmost engaging point **132** contacts the ground.

(15) In this embodiment, each of rear sprockets **124** may be powered by a rotationally coupled hydraulic motor so as drive left track **116** and right track **118** and thereby control propulsion and traction for work vehicle **100**. Each of the left and right hydraulic motors may receive pressurized hydraulic fluid from a hydrostatic pump whose direction of flow and displacement controls the direction of rotation and speed of rotation for the left and right hydraulic motors. Each hydrostatic pump may be driven by engine **134** of work vehicle **100**, and may be controlled by an operator in operator station **136** issuing commands which may be received by controller **138** and communicated to the left and right hydrostatic pumps by controller **138**. In alternative embodiments, each of rear sprockets **124** may be driven by a rotationally coupled electric motor or a mechanical system transmitting power from engine **134**.

(16) Top idlers **126** are longitudinally positioned between front idlers **120** and rear sprockets **124** along the left and right sides of work vehicle **100** above track rollers **122**. Similar to track rollers **122**, each of top idlers **126** may be rotationally coupled to left track **116** or right track **118** through engagement between a lower surface of the tracks and an upper surface of top idlers **126**. This configuration may allow top idlers **126** to support left track **116** and right track **118** for the longitudinal span between front idler **120** and rear sprocket **124**, and prevent downward deflection of the upper portion of left track **116** and right track **118** parallel to the ground between front idler **120** and rear sprocket **124**.

(17) Undercarriage **114** is affixed to, and provides support and tractive effort for, chassis **140** of work vehicle **100**. Chassis **140** is the frame which provides structural support and rigidity to work vehicle **100**, allowing for the transfer of force between implement **141**, depicted as blade **142**, and left track **116** and right track **118**. In this embodiment, chassis **140** is a weldment comprised of multiple formed and joined steel members, but in alternative embodiments it may be comprised of

any number of different materials or configurations. A chassis sensor **144** may be affixed to chassis **140** of work vehicle **100** and configured to provide a signal indicative of the movement and orientation of chassis **140**. In alternative embodiments, chassis sensor **144** may not be affixed directly to chassis **140**, but may instead be connected to chassis **140** through intermediate components or structures, such as rubberized mounts. In these alternative embodiments, chassis sensor **144** is not directly affixed to chassis **140** but is still connected to chassis **140** at a fixed relative position so as to experience the same motion as chassis **140**.

(18) The chassis sensor **144** may comprise at least one accelerometer and at least one gyroscope. Alternatively, the chassis sensor **144** may comprise an inertial measurement unit or IMU **196**. The chassis sensor **144** may comprise a global positioning system ("GPS") **146**. GPS **146** may comprise a Global Navigation Satellite System (GNSS), a terrestrial radio triangulation system, or any other system which is able to provide the location **150** of the work vehicle **100** in global or local coordinates. FIG. **2** illustratively shows that the work vehicle **100**, the chassis sensor **144**, the GPS **146**, and the controller **138** may be connected over a network **151**. Thus, computing architecture operates in a networked environment, where the network **151** includes any of a wide variety of different logical connections such as a local area network (LAN), wide area network (WAN), controller area network (CAN) near field communication network, satellite communication network, cellular networks, or a wide variety of other networks or combination of networks. It is also noted that the controller **138** can be deployed on the work vehicle **100** such that the controller **138** performs the operations described herein without a networked connection.

(19) With continued reference to FIGS. **1-2**, chassis sensor **144** or GPS **146** is configured to generate a chassis heading signal **148** indicative of a location **150** of the work vehicle **100**. The chassis heading signal **148** is an angular measurement in the direction of yaw **112**. The chassis heading signal **148** is indicative of a heading angle of a change from an initial heading to an updated heading.

(20) Chassis sensor **144** or GPS **146** is configured to generate a chassis inclination signal **152** indicative of a main fall angle, or inclination, of the chassis **140** relative to gravity or a bench surface **154** (FIG. **3**). The bench surface **154** may be provided via an input device **156** by an operator. The bench surface **154** may be a surface or plane that is defined by a roll **104** and pitch **108** relative to gravity and a vertical **110**, above sea level for example, that defines a depth. The bench surface **154** may be a surface that the work vehicle **100** is currently positioned on. The input device **156** may be a joystick. The chassis inclination signal **152** is an angular measurement in the direction of pitch **108**. Controller **138** may actuate blade **142** based on this chassis inclination signal **152**. As used herein, "based on" means "based at least in part on" and does not mean "based solely on," such that it neither excludes nor requires additional factors. Chassis sensor **144** may also be configured to provide a signal or signals indicative of other positions or velocities of chassis **140**, including, its angular position, velocity, or acceleration in a direction such as the direction of roll **104**, pitch **108**, yaw **112**, or its linear acceleration in a direction such as the direction of longitude **102**, latitude **106**, and vertical **110**. Chassis sensor **144** may be configured to directly measure inclination, measure angular velocity and integrate to arrive at inclination, or measure inclination and derive to arrive at angular velocity. Input device **156** may also be configured to provide a desired cross slope **158** relative to the bench surface **154**, a desired mainfall slope **160** relative to the bench surface **154**, and a desired depth **162** relative to the bench surface **154**.

(21) Chassis sensor **144** or GPS **146** is also configured to generate a chassis roll signal **164** indicative of a cross slope angle of the chassis **140** relative to the bench surface **154** or relative to the direction of gravity. The chassis roll signal **164** is an angular measurement in the direction of roll **104**.

(22) Implement **141** depicted as blade **142** may engage the ground or material to move or shape it. Blade **142** may be used to move material from one location to another and to create features on the

ground, including flat areas, grades, hills, roads, or more complexly shaped features. In this embodiment, blade **142** of work vehicle **100** may be referred to as a six-way blade, six-way adjustable blade, or power-angle-tilt (PAT) blade. Blade **142** may be hydraulically actuated to move vertically up or vertically down (which may also be referred to as blade lift, or raise and lower), roll left or roll right (which may be referred to as blade tilt, or tilt left and tilt right), and yaw left or yaw right (which may be referred to as blade angle, or angle left and angle right). Alternative embodiments may utilize a different implement **141** or a blade **142** with fewer hydraulically controlled degrees of freedom, such as a 4-way blade that may not be angled, or actuated in the direction of yaw **112**.

(23) Blade **142** is movably connected to chassis **140** of work vehicle **100** through linkage assembly **166**, which supports and actuates blade **142** and is configured to allow blade **142** to be raised or lowered relative to chassis **140** (i.e., moved in the direction of vertical **110**). Linkage assembly **166** may include multiple structural members to carry forces between blade **142** and the remainder of work vehicle **100** and may provide attachment points for hydraulic cylinders which may actuate blade **142** in the lift, tilt, and angle directions.

(24) Linkage assembly **166** includes c-frame **168**, a structural member with a C-shape positioned rearward of blade **142**, with the C-shape open toward the rear of work vehicle **100**. Each rearward end of c-frame **168** is pivotally connected to chassis **140** of work vehicle **100**, such as through a pin-bushing joint, allowing the front of c-frame **168** to be raised or lowered relative to work vehicle **100** about the pivotal connections at the rear of c-frame **168**. The front portion of c-frame **168**, which is approximately positioned at the lateral center of work vehicle **100**, connects to blade **142** through a ball-socket joint. This allows blade **142** three degrees of freedom in its orientation relative to c-frame **168** (lift-tilt-angle) while still transferring rearward forces on blade **142** to the remainder of work vehicle **100**.

(25) An implement sensor **170** may comprise at least one accelerometer and at least one gyroscope. Alternatively, the implement sensor **170** may comprise an inertial measurement unit or IMU **196**. The implement sensor **170** may be affixed to implement **141** or **142** above the ball-socket joint connecting blade **142** to c-frame **168**. Implement sensor **170**, like chassis sensor **144**, may be configured to measure angular position (inclination or orientation), velocity, or acceleration, or linear acceleration. Implement sensor **170** may provide an implement inclination signal **172**, which indicates the angle of blade **142** relative to one of the chassis **140** and the direction of gravity. The implement sensor **170** may be configured to provide an implement roll signal **174** indicative of an angle of the implement **141** in the roll **104** direction relative to one of the chassis **140** and the direction of gravity. The implement sensor **170** may be configured to provide an implement yaw signal **176** indicative of an angle of the implement **141** in the direction of yaw **112** relative to the chassis **140**.

(26) In alternative embodiments, an implement sensor **170** may be configured to instead measure an angle of linkage assembly **166**, such as an angle between linkage assembly **166** and chassis **140**, in order to determine a position of blade **142**. In other alternative embodiments, implement sensor **170** may be configured to measure a position of blade **142** by measuring a different angle, such as one between linkage assembly **166** and blade **142**, or the linear displacement of a cylinder attached to linkage assembly **166** or blade **142**. In alternative embodiments, implement sensor **170** may not be affixed directly to blade **142**, but may instead be connected to blade **142** through intermediate components or structures, such as rubberized mounts. In these alternative embodiments, implement sensor **170** is not directly affixed to blade **142** but is still connected to blade **142** at a fixed relative position so as to experience the same motion as blade **142**.

(27) Controller **138** is configured to receive the bench surface **154**, the desired cross slope **158**, the desired mainfall slope **160**, and the desired depth **162**, receive the chassis heading signal **148**, the chassis inclination signal **152**, and the chassis roll signal **164**, receive the implement inclination signal **172** and the implement roll signal **174**, determine an inclination distance error **178** based on

the chassis inclination signal **152** and the implement inclination signal **172**, the inclination distance error **178** indicative of a distance between the implement **141** and the desired mainfall slope **160**, determine a roll distance error **180** based on the chassis roll signal **164** and the implement roll signal **174**, the roll distance error **180** indicative of a distance between the implement **141** and the desired cross slope **158**, and send a command to move the implement **141** toward the desired mainfall slope **160** and the desired cross slope **158**, based on the inclination distance error **178** and the roll distance error **180**, and towards the desired depth **162**.

(28) Blade **142** may be raised or lowered relative to work vehicle **100** by the actuation of lift cylinders **182**, which may raise and lower c-frame **168** and thus raise and lower blade **142**, which may also be referred to as blade lift. For each of lift cylinders **182**, the rod end is pivotally connected to an upward projecting clevis of c-frame **168** and the head end is pivotally connected to the remainder of work vehicle **100** just below and forward of operator station **136**. The configuration of linkage assembly **166** and the positioning of the pivotal connections for the head end and rod end of lift cylinders **182** results in the extension of lift cylinders **182** lowering blade **142** and the retraction of lift cylinders **182** raising blade **142**. In alternative embodiments, blade **142** may be raised or lowered by a different mechanism, or lift cylinders **182** may be configured differently, such as a configuration in which the extension of lift cylinders **182** raises blade **142** and the retraction of lift cylinders **182** lowers blade **142**.

(29) Blade **142** may be tilted relative to work vehicle **100** by the actuation of tilt cylinder **184**, which may also be referred to as moving blade **142** in the direction of roll **104**. For tilt cylinder **184**, the rod end is pivotally connected to a clevis positioned on the back and left sides of blade **142** above the ball-socket joint between blade **142** and c-frame **168** and the head end is pivotally connected to an upward projecting portion of linkage assembly **166**. The positioning of the pivotal connections for the head end and the rod end of tilt cylinder **184** result in the extension of tilt cylinder **184** tilting blade **142** to the left or counterclockwise when viewed from operator station **136** and the retraction of tilt cylinder **184** tilting blade **142** to the right or clockwise when viewed from operator station **136**. In alternative embodiments, blade **142** may be tilted by a different mechanism (e.g., an electrical or hydraulic motor) or tilt cylinder **184** may be configured differently, such as a configuration in which it is mounted vertically and positioned on the left or right side of blade **142**, or a configuration with two tilt cylinders **184**.

(30) Blade **142** may be angled relative to work vehicle **100** by the actuation of angle cylinders **186**, which may also be referred to as moving blade **142** in the direction of yaw **112**. For each of angle cylinders **186**, the rod end is pivotally connected to a clevis of blade **142** while the head end is pivotally connected to a clevis of c-frame **168**. One of angle cylinders **186** is positioned on the left side of work vehicle **100**, left of the ball-socket joint between blade **142** and c-frame **168**, and the other of angle cylinders **186** is positioned on the right side of work vehicle **100**, right of the ball-socket joint between blade **142** and c-frame **168**. This positioning results in the extension of the left of angle cylinders **186** and the retraction of the right of angle cylinders **186** angling blade **142** rightward, or yawing blade **142** clockwise when viewed from above, and the retraction of left of angle cylinder **186** and the extension of the right of angle cylinders **186** angling blade **142** leftward, or yawing blade **142** counterclockwise when viewed from above. In alternative embodiments, blade **142** may be angled by a different mechanism or angle cylinders **186** may be configured differently.

(31) Due to the geometry of linkage assembly **166** in this embodiment, blade **142** is not raised or lowered in a perfectly vertical line with respect to work vehicle **100**. Instead, a point on blade **142** would trace a curve as blade **142** is raised and lowered. This means that the vertical component of the velocity of blade **142** is not perfectly proportional to the linear velocity with which lift cylinders **182** are extending or retracting, and the vertical component of blade **142**'s velocity may vary even when the linear velocity of lift cylinders **182** is constant. This also means that lift cylinders **182** have a mechanical advantage which varies depending on the position of linkage assembly **166**. Given a kinematic model of blade **142** and linkage assembly **166** (e.g., formula(s) or table(s)

providing a relationship between the position and/or movement of portions of blade **142** and linkage assembly **166**) and the state of blade **142** and linkage assembly **166** (e.g., sensor(s) sensing one or more positions, angles, or orientations of blade **142** or linkage assembly **166**, such as implement sensor **170**), at least with respect to blade lift, controller **138** may compensate for such non-linearity. Incomplete or simplified kinematic models may be used if there is a need to only focus on particular motion relationships (e.g., only those affecting blade lift) or if only limited compensation accuracy is desired. Controller **138** may utilize this compensation and a desired velocity, for example a command to raise blade **142** at a particular vertical velocity, to issue a command that may achieve a flow rate into lift cylinders **182** that results in blade **142** being raised at the particular vertical velocity regardless of the current position of linkage assembly **166**. For example, controller **138** may issue commands which vary the flow rate into lift cylinders **182** in order to achieve a substantially constant vertical velocity of blade **142**.

(32) Similarly, due to the positioning of tilt cylinder **184** and angle cylinders **186** and the configuration of their connection to blade **142**, the angular velocity of blade tilt and angle is not perfectly proportional to the linear velocity of tilt cylinder **184** and angle cylinders **186**, respectively, and the angular velocity of tilt and angle may vary even when the linear velocity of tilt cylinder **184** and angle cylinders **186**, respectively, is constant. This also means that tilt cylinder **184** and angle cylinders **186** each has a mechanical advantage which varies depending on the position of blade **142**. Much like with lift cylinders **182**, given a kinematic model of blade **142** and linkage assembly **166**, and the state of blade **142** and linkage assembly **166**, at least with respect to blade tilt and angle, controller **138** may compensate for such non-linearity. Incomplete or simplified kinematic models may be used if there is a need to only focus on particular motion relationships (e.g., only those affecting blade tilt and angle) or if only limited compensation accuracy is required. Controller **138** may utilize this compensation and a desired angular velocity, for example a command to tilt or angle blade **142** at a particular angular velocity, to issue commands that may vary the flow rate into tilt cylinder **184** or angle cylinders **186** to result in blade **142** being tilted or angled at the particular angular velocity regardless of the current position of blade **142** or linkage assembly **166**.

(33) In alternative embodiments, blade **142** may be connected to the remainder of work vehicle **100** in a manner which tends to make the blade lift velocity (in direction of vertical **110**), tilt angular velocity (in the direction of roll **104**), or angle angular velocity (in the direction of yaw **112**) proportional to the linear velocity of lift cylinders **182**, tilt cylinder **184**, or angle cylinders **186**, respectively. This may be achieved with particular designs of linkage assembly **166** and positioning of the pivotal connections of lift cylinders **182**, tilt cylinder **184**, and angle cylinders **186**. In such alternative embodiments, controller **138** may not need to compensate for non-linear responses of blade **142** to the actuation of lift cylinders **182**, tilt cylinder **184**, and angle cylinders **186**, or the need for compensation may be reduced.

(34) Each of lift cylinders **182**, tilt cylinder **184**, and angle cylinders **186** is a double acting hydraulic cylinder. One end of each cylinder may be referred to as a head end, and the end of each cylinder opposite the head end may be referred to as a rod end. Each of the head end and the rod end may be fixedly connected to another component or, as in this embodiment, pivotally connected to another component, such as a through a pin-bushing or pin-bearing coupling, to name but two examples of pivotal connections. As a double acting hydraulic cylinder, each may exert a force in the extending or retracting direction. Directing pressurized hydraulic fluid into a head chamber of the cylinders will tend to exert a force in the extending direction, while directing pressurized hydraulic fluid into a rod chamber of the cylinders will tend to exert a force in the retracting direction. The head chamber and the rod chamber may both be located within a barrel of the hydraulic cylinder, and may both be part of a larger cavity which is separated by a movable piston connected to a rod of the hydraulic cylinder. The volumes of each of the head chamber and the rod chamber change with movement of the piston, while movement of the piston results in extension or

retraction of the hydraulic cylinder. The control of these cylinders will be described in further detail with regard to FIG. **2**.

(35) FIG. **4** is a schematic of a portion of a system for controlling the hydraulic cylinder, the system including hydraulic and electrical components. Each of lift cylinders **182**, tilt cylinder **184**, and angle cylinders **186** is hydraulically connected to hydraulic control valve **188**, which may be positioned in an interior area of work vehicle **100**. Hydraulic control valve **188** may also be referred to as a valve assembly or manifold. Hydraulic control valve **188** receives pressurized hydraulic fluid from hydraulic pump **190**, which may be rotationally connected to engine **134**, and directs such fluid to lift cylinders **182**, tilt cylinder **184**, angle cylinders **186**, and other hydraulic circuits or functions of work vehicle **100**. Hydraulic control valve **188** may meter such fluid out, or control the flow rate of hydraulic fluid to each hydraulic circuit to which it is connected. In alternative embodiments, hydraulic control valve **188** may not meter such fluid out but may instead only selectively provide flow paths to these functions while metering is performed by another component (e.g., a variable displacement hydraulic pump) or not performed at all. Hydraulic control valve **188** may meter such fluid out through a plurality of spools, whose positions control the flow of hydraulic fluid, and other hydraulic logic. The spools may be actuated by solenoids, pilots (e.g., pressurized hydraulic fluid acting on the spool), the pressure upstream or downstream of the spool, or some combination of these and other elements.

(36) In the embodiment illustrated in FIG. **1**, the spools of hydraulic control valve **188** are shifted by pilots whose pressure is controlled, at least in part, by electrohydraulic pilot valve **192** in communication with controller **138**. Electrohydraulic pilot valve **192** is positioned within an interior area of work vehicle **100** and receives pressurized hydraulic fluid from a hydraulic source and selectively directs such fluid to pilot lines hydraulically connected to hydraulic control valve **188**. In this embodiment hydraulic control valve **188** and electrohydraulic pilot valve **192** are separate components, but in alternative embodiments the two valves may be integrated into a single valve assembly or manifold. In this embodiment, the hydraulic source is hydraulic pump **190**. In alternative embodiments, a pressure reducing valve may be used to reduce the pressure of pressurized hydraulic fluid provided by hydraulic pump **190** to a set pressure, for example 600 pounds per square inch, for usage by electrohydraulic pilot valve **192**. In the embodiment illustrated in FIG. **2**, individual valves within electrohydraulic pilot valve **192** reduce the pressure from the received hydraulic fluid via solenoid-actuated spools which may drain hydraulic fluid to a hydraulic reservoir. In this embodiment, controller **138** actuates these solenoids by sending a specific current to each (e.g., 600 mA). In this way, controller **138** may actuate blade **142** by issuing electrical commands signals to electrohydraulic pilot valve **192**, which in turn provides hydraulic signals (pilots) to hydraulic control valve **188**, which shift spools to direct hydraulic flow from hydraulic pump **190** to actuate lift cylinders **182**, tilt cylinder **184**, and angle cylinders **186**. In this embodiment, controller **138** is in direct communication with electrohydraulic pilot valve **192** via electrical signals sent through a wire harness and is indirectly in communication with hydraulic control valve **188** via electrohydraulic pilot valve **192**.

(37) Controller **138**, which may be referred to as a vehicle control unit (VCU), is in communication with a number of components on work vehicle **100**, including hydraulic components such as electrohydraulic pilot valve **192**, electrical components such as operator inputs within operator station **136**, chassis sensor **144**, implement sensor **170**, and other components. Controller **138** is electrically connected to these other components by a wiring harness such that messages, commands, and electrical power may be transmitted between controller **138** and the remainder of work vehicle **100**. Controller **138** may be connected to some of these sensors or other controllers, such as an engine control unit (ECU), through a controller area network (CAN). Controller **138** may then send and receive messages over the CAN to communicate with other components on the CAN.

(38) In alternative embodiments, controller **138** may send a command to actuate blade **142** in a

number of different manners. As one example, controller **138** may be in communication with a valve controller via a CAN and may send command signals to the valve controller in the form of CAN messages. The valve controller may receive these messages from controller **138** and send current to specific solenoids within electrohydraulic pilot valve **192** based on those messages. As another example, controller **138** may actuate blade **142** by actuating an input in operator station **136**. For example, an operator may use input device **156** (e.g., joystick) to issue commands to actuate blade **142**, and the joystick may generate hydraulic pressure signals, pilots, which are communicated to hydraulic control valve **188** to cause the actuation of blade **142**. In such a configuration, controller **138** may be in communication with electrical devices (e.g., solenoids, motors) which may actuate a joystick in operator station **136**. In this way, controller **138** may actuate blade **142** by actuating these electrical devices instead of communicating signals to electrohydraulic pilot valve **192**.

(39) FIG. **5** is a left side view of work vehicle **100** as work vehicle **100** drives over ground feature **194**, which in this example is a ground feature at a higher elevation than the surrounding ground surface (e.g., an upward ground feature). As work vehicle **100** drives over ground feature **194**, frontmost engaging point **130** is the first point on left track **116** and right track **118** which substantially engages ground feature **194**. As work vehicle **100** engages ground feature **194** at frontmost engaging point **130**, work vehicle **100** begins to pitch upward or pitch backward as the front of work vehicle **100** rises on ground feature **194** relative to the rear of work vehicle **100**. When pitching upwards or backwards, work vehicle **100** will tend to pitch about rearmost engaging point **132**.

(40) During this pitching, chassis sensor **144** may send a chassis inclination signal **152** indicative of the angle of chassis **140** relative to the direction of gravity (i.e., orientation in the direction of pitch **108**) as well as a chassis pitch signal indicative of an angular velocity of chassis **140** in the direction of pitch **108**. The chassis inclination signal **152** and chassis pitch signal will indicate an inclination and velocity in a first direction, angled and pitching upwards, as opposed to the chassis inclination signal **152** and chassis pitch signal indicating an inclination and velocity in a second direction, angled and pitching downwards. In this embodiment, chassis inclination signal **152** and chassis pitch signal from chassis sensor **144** to controller **138** may indicate values within a range for which values in one half of the range indicate angles and angular velocities in the first direction and values in the other half of the range indicate angles and angular velocities in the second direction. During the pitching, chassis sensor **144** may also send the chassis roll signal **164** and the chassis heading signal **148**. The signals from chassis sensor **144** may be received by the controller **138**.

(41) Similarly, implement sensor **170** may send an implement inclination signal **172** indicative of the angle of blade **142** relative to the direction of gravity (i.e., orientation in the direction of pitch **108**) as well as an implement pitch signal indicative of an angular velocity of blade **142** in the direction of pitch **108**. The implement inclination signal **172** and implement pitch signal will indicate an inclination and velocity in a first direction, angled and pitching upwards, as opposed to the implement inclination signal **172** and implement pitch signal indicating an inclination and velocity in a second direction, angled and pitching downwards. In this embodiment, implement inclination signal **172** and implement pitch signal from implement sensor **170** to controller **138** may indicate values within a range for which values in one half of the range indicate angles and angular velocities in the first direction and values in the other half of the range indicate angles and angular velocities in the second direction. During the pitching, implement sensor **170** may also send the implement roll signal **174** and the implement yaw signal **176**. The signals from the implement sensor **170** may be received by the controller **138**.

(42) As work vehicle **100** continues to drive over ground feature **194**, frontmost engaging point **130** would cease to engage the ground and instead would remain suspended above the ground by a distance determined in part by the height of ground feature **194** relative to the surrounding ground

surface and the position of work vehicle **100** on ground feature **194**. At this point, although ground feature **194** is an upward ground feature, it has the effect of a downward ground feature at a lower elevation than the surrounding ground surface. Specifically, the area just past ground feature **194** is lower than ground feature **194**. As the center of gravity for work vehicle **100** passes over the top of ground feature **194**, work vehicle **100** will pitch forwards and rearmost engaging point **132** will leave the ground surface while frontmost engaging point **130** will fall until it contacts the ground surface.

(43) During the process of work vehicle **100** driving over ground feature **194**, blade **142** will rise and fall relative to the ground surface due to the pitching of work vehicle **100**. As work vehicle **100** pitches backward, blade **142** will rise as c-frame **168** pitches backward with work vehicle **100**, and as work vehicle **100** pitches forward, blade **142** will fall as c-frame **168** pitches forward with work vehicle **100**. If the operator of work vehicle **100** fails to correct for ground feature **194** by commanding blade **142** to rise or fall in a manner that counteracts the effect of ground feature **194** on the height of blade **142**, work vehicle **100** will create vertical variations on the ground surface instead of a smooth surface, such as a hill and a valley. As work vehicle **100** drives over this newly created hill and valley on the ground surface, blade **142** will once again be raised and lowered as work vehicle **100** pitches backward and forward, creating further vertical variations. This series of hills and valleys may be referred to as a “washboard” pattern. In addition to creating this pattern, the pitching of work vehicle **100** will also interrupt efforts to maintain a uniform grade. An operator of work vehicle **100** may target a particular grade (e.g., 2%) and if traveling up or down the grade, the pitching of work vehicle **100** will create segments where the actual grade is steeper or shallower than the target grade.

(44) While this is occurring, chassis sensor **144** and implement sensor **170** send the chassis inclination signal **152**, chassis pitch signal, chassis roll signal **164**, chassis heading signal **148**, implement inclination signal **172**, implement roll signal **174**, implement yaw signal **176**, and implement pitch signal to controller **138**. Controller **138** may also receive signals from controls in operator station **136** which the operator may use to issue commands, for example a command to raise or lower blade **142**. If controller **138** does not sense a command from the operator to raise or lower blade **142**, but receives a signal from chassis sensor **144** or implement sensor **170** indicating that chassis **140** or blade **142** is pitching, controller **138** may issue a command to electrohydraulic pilot valve **192** to raise or lower blade **142** to counteract the effect from the pitch. In this manner, controller **138** may attempt to mitigate or attenuate the effect of pitching and ground features and thereby create a smoother ground surface, as further described with regard to FIG. **6**.

(45) In this embodiment, each of chassis sensor **144** and implement sensor **170** comprise three accelerometers, each measuring linear acceleration in one of three perpendicular directions, and three gyroscopes, each measuring angular velocity in one of three perpendicular directions. In this way, chassis sensor **144** and implement sensor **170** may each directly measure linear acceleration or angular velocity in any direction, including the directions of longitude **102**, latitude **106**, vertical **110**, roll **104**, pitch **108**, and yaw **112**. The linear acceleration of each accelerometer may be filtered to remove short term accelerations or otherwise analyzed to determine the direction of gravity, which exerts a constant acceleration of approximately 9.81 meters per square second on chassis sensor **144** and implement sensor **170**. The measurements from the accelerometers and gyroscopes of chassis sensor **144** and implement sensor **170** may be combined or analyzed together to improve the accuracy and/or reduce the latency with which the direction of gravity may be determined. For example, the accelerometers may measure the direction of gravity with high accuracy over a period of time sufficient to remove the effects of short-term accelerations, while the gyroscopes may measure changes to the direction of the sensor relative to the direction of gravity very quickly but be subject to drift if these changes are integrated to determine the direction and error is allowed to accumulate. Chassis sensor **144** and implement sensor **170** may each be an IMU “inertial measurement unit” **196**.

(46) FIG. **3** illustrates how controller **138** may issue commands to move blade **142** so as to counteract pitching, such as may happen when the tracks of work vehicle **100** engage ground features. As work vehicle **100** travels in a forward direction, it creates profile **400**, which illustrates a cross-section of the ground which work vehicle **100** is working. Controller **138** may determine a target grade, including based on an operator directly entering a desired cross slope **158**, a desired mainfall slope **160**, a desired depth **162**, and a bench surface **154** or a grade (e.g., 2%) via the input device **156** or by recording the current grade after an operator is done issuing blade commands. This target grade, which may also be referred to as a target angle or target plane, is illustrated by line **402** in FIG. **3**. While line **402** illustrates the target grade while work vehicle **100** is on slope **404**, it does not represent the target grade while work vehicle **100** is on different portions of profile **400**.

(47) As work vehicle **100** travels forward, it may create slope **404** which is at the target grade. As work vehicle **100** continues travelling forward, it may encounter a ground feature (e.g., a rock) at point **406**, at which point work vehicle **100** will begin pitching upwards. Absent a counteracting command, this may cause blade **142** to pitch upwards and create slope **408**, which is at a different grade than target grade. Controller **138**, receiving chassis inclination signal **152**, chassis pitch signal, chassis roll signal **164**, chassis heading signal **148**, implement inclination signal **172**, implement roll signal **174**, implement yaw signal **176**, and implement pitch signal, may detect this change and issue commands to move the blade **142** downwards to counteract the ground feature encountered at point **406**. By point **410**, controller **138** may have corrected for the ground feature so that blade **142** of work vehicle **100** creates slope **412**, which is once again at the target grade. Slope **412** is parallel to slope **404**, but at a different elevation due to the increase in elevation by work vehicle **100** overall. If line **402** were updated to reflect the current target slope of work vehicle **100**, line **402** would overlay slope **412** while work vehicle **100** was on that portion of profile **400**. As work vehicle **100** continues to operate, it may continue to create a series of plateaus and slopes as in encounters ground features and controller **138** commands movement of blade **142** to counteract these ground features.

(48) FIG. **6** is a flowchart of a method **500** of controlling a ground-engaging implement **141** of a work vehicle **100**. In step **502**, a bench surface **154**, a desired cross slope **158** relative to the bench surface **154**, a desired mainfall slope **160** relative to the bench surface **154**, and a desired depth **162** relative to the bench surface **154** is received. In step **504**, a chassis inclination signal **152** indicative of a main fall angle of a chassis **140** of the work vehicle **100** relative to the bench surface **154** is received. In step **506**, an implement inclination signal **172** indicative of an angle of the implement **141** relative to one of the chassis **140** and the direction of gravity is received. In step **508**, a chassis roll signal **164** indicative of a cross slope angle of the chassis **140** relative to the bench surface **154** is received. In step **510**, an implement roll signal **174** indicative of an angle of the implement **141** in the roll direction relative to one of the chassis **140** and the direction of gravity is received. In step **512**, a chassis heading signal **148** indicative of a location **150** of the work vehicle **100** is received. In step **514**, an inclination distance error **178** based on the chassis inclination signal **152** and the implement inclination signal **172**, the inclination distance error **178** indicative of a distance between the implement **141** and the desired mainfall slope **160** is determined. In step **516**, a roll distance error **180** is determined based on the chassis roll signal **164** and the implement roll signal **174**, the roll distance error **180** indicative of a distance between the implement **141** and the desired cross slope **158**. In step **518**, the work vehicle **100** is controlled to move the implement **141** toward the desired mainfall slope **160** and the desired cross slope **158**, based on the inclination distance error **178** and the roll distance error **180**, and towards the desired depth **162**.

(49) FIG. **7** shows another work vehicle **100** that may be used for similar operations or tasks as the crawler **101**, which is a motor grader **600**. The motor grader **600** includes a chassis **140** that is supported by wheels **602**. The motor grader **600** includes an implement **141** depicted as a blade **142**. The implement may be lifted with lift cylinders **182**. The motor grader **600** is powered by an

engine **134**. The motor grader **600** includes an operator station **136** that includes an input device **156**. The motor grader **600** includes a chassis sensor **144** that may be a GPS **146** and an implement sensor **170** that is in communication with a controller **138**.
(50) While the disclosure has been illustrated and described in detail in the drawings and foregoing description, such illustration and description is not restrictive in character, it being understood that illustrative embodiment(s) have been shown and described and that all changes and modifications that come within the spirit of the disclosure are desired to be protected.
(51) Alternative embodiments of the present disclosure may not include all of the features described yet still benefit from at least some of the advantages of such features. Those of ordinary skill in the art may devise their own implementations that incorporate one or more of the features of the present disclosure and fall within the spirit and scope of the appended claims.

Claims

1. A work vehicle comprising: a chassis; a ground-engaging implement movably connected to the chassis via a linkage assembly configured to allow the implement to be raised and lowered relative to the chassis and moved in a roll direction relative to the chassis; an input device for providing a bench surface, a desired cross slope relative to the bench surface, a desired mainfall slope relative to the bench surface, and a desired depth relative to the bench surface; a global positioning system communicatively coupled to the work vehicle, the global positioning system configured for generating a chassis heading signal indicative of a location of the work vehicle, a chassis inclination signal indicative of a main fall angle of the chassis relative to the bench surface, and a chassis roll signal indicative of a cross slope angle of the chassis relative to the bench surface; an implement sensor configured to provide an implement inclination signal indicative of an angle of the implement relative to one of the chassis and the direction of gravity and an implement roll signal indicative of an angle of the implement in the roll direction relative to one of the chassis and the direction of gravity; and a controller configured to: receive the bench surface, the desired cross slope, the desired mainfall slope, and the desired depth; receive the chassis heading signal, the chassis inclination signal, and the chassis roll signal; receive the implement inclination signal and the implement roll signal; determine an inclination distance error based on the chassis inclination signal and the implement inclination signal, the inclination distance error indicative of a distance between the implement and the desired mainfall slope; determine a roll distance error based on the chassis roll signal and the implement roll signal, the roll distance error indicative of a distance between the implement and the desired cross slope; and send a command to move the implement toward the desired mainfall slope and the desired cross slope, based on the inclination distance error and the roll distance error, and towards the desired depth.
2. The work vehicle of claim 1, wherein the implement sensor comprises at least one accelerometer and at least one gyroscope.
3. The work vehicle of claim 1, wherein the implement sensor comprises an IMU.
4. The work vehicle of claim 1, wherein the linkage assembly is configured to allow the implement to be moved in a yaw direction.
5. The work vehicle of claim 1, wherein the implement comprises a blade.
6. The work vehicle of claim 1, wherein the work vehicle is a crawler.
7. The work vehicle of claim 1, wherein the work vehicle is a motor grader.
8. The work vehicle of claim 1, wherein the implement sensor is coupled to the implement.
9. A method of controlling a ground-engaging implement of a work vehicle comprising: receiving a bench surface, a desired cross slope relative to the bench surface, a desired mainfall slope relative to the bench surface, and a desired depth relative to the bench surface; receiving a chassis inclination signal indicative of a main fall angle of a chassis of the work vehicle relative to the bench surface; receiving an implement inclination signal indicative of an angle of the implement

relative to one of the chassis and the direction of gravity; receiving a chassis roll signal indicative of a cross slope angle of the chassis relative to the bench surface; receiving an implement roll signal indicative of an angle of the implement in the roll direction relative to one of the chassis and the direction of gravity; receiving a chassis heading signal indicative of a location of the work vehicle; determining an inclination distance error based on the chassis inclination signal and the implement inclination signal, the inclination distance error indicative of a distance between the implement and the desired mainfall slope; determining a roll distance error based on the chassis roll signal and the implement roll signal, the roll distance error indicative of a distance between the implement and the desired cross slope; and controlling the work vehicle to move the implement toward the desired mainfall slope and the desired cross slope, based on the inclination distance error and the roll distance error, and towards the desired depth.

10. The method of claim 9, wherein the work vehicle is a crawler.

11. The method of claim 9, wherein the work vehicle is a motor grader.

12. A crawler comprising: a chassis; a ground-engaging implement movably connected to the chassis by a linkage assembly configured to allow the implement to be raised and lowered relative to the chassis and moved in a roll direction relative to the chassis; a hydraulic cylinder; an electrohydraulic valve assembly configured to move the implement by directing hydraulic fluid to the hydraulic cylinder; an input device for providing a bench surface, a desired cross slope relative to the bench surface, a desired mainfall slope relative to the bench surface, and a desired depth relative to the bench surface; a global positioning system communicatively coupled to the crawler, the global positioning system configured for generating a chassis heading signal indicative of a location of the crawler, a chassis inclination signal indicative of a main fall angle of the chassis relative to the bench surface, and a chassis roll signal indicative of a cross slope angle of the chassis relative to the bench surface; an implement sensor coupled to the implement configured to provide an implement inclination signal indicative of an angle of the implement relative to one of the chassis and the direction of gravity and an implement roll signal indicative of an angle of the implement in the roll direction relative to one of the chassis and the direction of gravity; and a controller configured to: receive the bench surface, the desired cross slope, the desired mainfall slope, and the desired depth; receive the chassis heading signal, the chassis inclination signal, and the chassis roll signal; receive the implement inclination signal and the implement roll signal; determine an inclination distance error based on the chassis inclination signal and the implement inclination signal, the inclination distance error indicative of a distance between the implement and the desired mainfall slope; determine a roll distance error based on the chassis roll signal and the implement roll signal, the roll distance error indicative of a distance between the implement and the desired cross slope; and send a command to the electrohydraulic valve assembly to move the implement toward the desired mainfall slope and the desired cross slope, based on the inclination distance error and the roll distance error, and towards the desired depth.

13. The crawler of claim 12, wherein the implement sensor comprises at least one accelerometer and at least one gyroscope.

14. The crawler of claim 12, wherein the implement sensor comprises an IMU.

15. The crawler of claim 12, wherein the implement sensor is coupled to the implement.

16. The crawler of claim 12, wherein the linkage assembly is configured to allow the implement to be moved in a yaw direction.

17. The crawler of claim 12, wherein the implement comprises a blade.